

Article

Study of the Presence of Sustainability Competencies in Teacher Training in Mathematics Education

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Abstract: This article presents the results of the analysis of the presence of the sustainability competencies proposed by the Sectoral Commission of the Conference of Rectors of Spanish Universities in three degrees in the area of Didactics of Mathematics of the Faculty of Education Sciences at the Universidad de Cádiz (Spain): the degree in Early Childhood Education, the degree in Primary Education, and the Master's degree in Teacher Training for Compulsory Secondary and Upper Secondary School Education (specialisation in mathematics). The research method used is content analysis, reflected in the syllabi of the subjects of the degrees analysed. To carry out the analysis, two instruments were used: an adaptation of the model of the Green Curriculum in Higher Education and the map of generic competencies in sustainability of the EDINSOST project. The global results show a very low relative presence of sustainability competences in the area of Didactics of Mathematics (25%), the competency related to ethical aspects having the lowest relative presence (10%). For the most part, the competencies related to sustainability are established for the lowest level of mastery, "know". When comparing the degree programmes, the Master's degree in Teacher Training for Compulsory Secondary and Upper Secondary School Education (specialisation in mathematics) is the degree that contributes the most to the development of the sustainability competency (32%), followed by the degree in Early Childhood Education (25%), and the degree in Primary Education (18%). Including sustainability in the curriculum of mathematics education in higher education can improve the training of professionals who engage in reflective and critical thinking. However, these results show there is still a long way to go.

Keywords: Higher Education; curriculum for sustainability; sustainability competencies; critical mathematics education; teacher training; EDINSOST project



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1. Introduction

At the dawn of the 20th century, Laisant and Fehr [1] stated how the future of civilisation would, to a large extent, depend on the direction of thought the new generations received with respect to science and, in particular, mathematics. Today, the firm belief in the need for the teaching of mathematics as a discipline that brings with it scientific and technological progress, enhancing the development and modernisation of societies, is undeniable.

From the second half of the 20th century and after the Second World War, the world entered a new dynamic: globalisation. Currently, humanity faces a multitude of new and old problems: climate change, desertification, water scarcity, poverty, health, hunger, wars, problems of logistics, migration, social inequalities, excessive digital traffic, etc. Today's industrialised and mechanised society is fraught with conflicts and crises [2]. In an increasingly complex world, tending towards a technical rationality in which it trusts to be able to solve these (human) problems, it is more necessary than ever to question the aims of education in general and mathematics education in particular.

The society of the new century demands that schools prepare well-informed citizens with more mathematical culture, capable of expanding their learning with equal opportunities [3]. Many of today's issues like environmental protection, nuclear energy, defence spending, space exploration, genetic engineering, paying taxes, connectivity, etc. require training citizens capable of reading and interpreting complex and often contradictory information [3]. Niss affirms that "it is of democratic importance to the individual as well as to society at large that any citizen is provided with the instruments for understanding the role of mathematics", and adds "anyone not in possession of such instruments becomes victim of social processes in which mathematics is a component" [4] (p. 248). However, as Skovsmose [2] asserts, these instruments do not have to be mathematical in themselves. "The missing competency need not be identical with some mathematical competency" [2] (p. 58). The complex multiplicity of what is human [5] requires adopting a complex view of mathematics itself as an object of teaching and learning, not limiting its purpose to the exclusive development of the competency that we commonly refer to as mathematical skills [6]. It is also necessary to "incorporate citizenship training of people as an intrinsic purpose of mathematics education" [6] (p. 248). Mathematical literacy is situated along this line, as a competency that integrates not only mathematical and technological knowing, but also reflective knowing, referring to the ability to reflect on the use of mathematics, that is, on the social and ethical consequences that could derive from its application and could create an awareness of conflicts [2]. The planetary crisis is of a political nature, and needs politics, since it affects the culture that we have given ourselves as societies. As Andrade-Molina and Valero [7] state, bringing ethics to the centre of mathematics education is also a way of approaching politics from mathematics. A powerful alternative that would allow the development of reflective knowing as an inherent part of mathematics literacy is to advocate for the curriculum of mathematics education to be more sustainable. The integration of eminently ethical competencies such as those of sustainability in the training of teachers in mathematics education would allow creating an awareness of conflicts and critical structures in society.

In recent decades, several national and international initiatives have been aimed at universities assuming a leadership role to promote education for sustainable development and respond to the global challenges of today's society. Education for sustainable development plays a key role in higher education degrees for the training of agents of change and social transformation. Working towards achieving the sustainable development goals (SDGs) of the 2030 agenda is a widely recognised [8] and accepted framework by different governments, representatives of civil society, and several economic and business sectors of various countries in the world [9]. Target 4.7 of SDG 4, quality education, establishes the importance of ensuring students acquire theories and practices that promote sustainable development and global citizenship [10].

The idea of incorporating sustainability into the curriculum was born with the aim of training professionals that engage in critical thinking and are committed to improving their local environment in their daily lives, able to understand and interpret the world in terms of relationships [11], and confident that their actions can make a difference in society [12]. Making education sustainable refers to designing educational programmes, from the different areas of knowledge, that enable training professionals who can experience real situations promoting reflection, taking into account values of justice, solidarity, equity, ethics, and respect for diversity [13].

Many researchers have discussed the inclusion of sustainability principles in university curricula and although there is much debate about this aspect, there is also a broad consensus on the need to provide future graduates with competency-based training [14,15].

In the international framework, a basic reference for incorporating sustainability into the curriculum is the Green Curriculum Network in Higher Education (ACES Network), created in 2000 within the Alfa programme of the European Union. One of the important results of this project was the definition of a series of criteria that allows the diagnosis of an environmental study characterising it. Subsequent research [16] established an educational

competency framework for sustainability in the training of future teachers based on these criteria. Wiek, Withycombe, and Redman [17] identify systems thinking, anticipatory competency, normative knowledge, and strategic knowledge as competencies related to sustainability. The United Nations Educational Scientific and Cultural Organisation [18] adds the competencies of critical thinking, problem-solving, collaboration, self-awareness, and reflection to the above-mentioned competencies.

In Spain, the Sectoral Commission of the Conference of Rectors of Spanish Universities CRUE-Sustainability [19] approved the “Guidelines for the introduction of sustainability in the curriculum” document in 2005, and it was updated in 2012. The following four cross-curricular competencies for sustainability are put forward in this document:

- SUS1: Competency in the critical contextualisation of knowledge through interrelating social, economic, and environmental issues at a local and/or global scale.
- SUS2: Competency in the sustainable use of resources and in the prevention of negative impacts on the natural and social environment.
- SUS3: Competency to participate in community processes that promote sustainability.
- SUS4: Competency to apply ethical principles related to sustainability values in personal and professional behaviour.

The CRUE-Sustainability asked the university community for “the comprehensive review of the curricula ensuring the inclusion of the basic cross-curricular contents in sustainability in all the degrees in agreement with the competencies defined” [19] (p. 7).

To achieve the sustainable development goals of the 2030 Agenda, a holistic, inclusive, and transformational education [18], which brings with it the need to promote professional growth in initial teacher training [20], is necessary. However, while much has been written about rethinking teacher training towards sustainability [21], there is a lack of important literature that unravels the connections between teacher training in mathematics education and sustainability [22]. Alsina and Calabuig [23] defined a model for the initial training of mathematics teachers based on five dimensions: links with the environment, didactic-disciplinary knowledge, reflective and critical thinking, children’s needs to learn and curricular environmentalisation.

Making mathematics education more sustainable requires an in-depth study of what elements would make it possible. A first step in that direction is to diagnose the current situation in which mathematics education training finds itself to be able to evaluate the problem.

This article presents the results of the analysis of the presence of the sustainability competencies defined by the CRUE-Sustainability [19] in the area of Didactics of Mathematics of the Faculty of Education Sciences at the Universidad de Cádiz (Spain). The scope of this work is limited to the Professional Development Research Group of the Teacher-HUM462 of the Universidad de Cádiz, within the framework of the EDINSOST project [24] in which we participate.

2. Materials and Methods

This paper presents the partial results of a more general research [25] situated in the EDINSOST research project: Education and Social Innovation for Sustainability, training of professionals as agents of change in Spanish universities to address the challenges of society (Reference: EDU2015-65574-R). One of the objectives of this project was to develop a rubric or map of generic sustainability competencies of the degrees participating in the project and establish the framework of action that facilitates their integration into the different degree programmes in a holistic manner [24,26]. This map of generic sustainability competencies is, amongst others, used as an analytical tool in this study (see Section 2.3).

The documents that make up the syllabi (study programmes) of the subjects taught in the area of Didactics of Mathematics at the Universidad de Cádiz were the main source of information. In this regard, it is a case study whose research technique is documentary analysis.

2.1. Research Objective and Questions

The present paper aims to analyse the presence of the sustainability competencies defined by the CRUE-Sustainability [19] in the study programmes of the subjects of the area of Didactics in Mathematics at the Universidad de Cádiz. For this purpose, we put forward four research questions. The choice of these research questions is justified in the literature of the EDINSOST project, and, more specifically, in the creation of a sustainability competency map, resulting from this same project, as an analytical tool.

- Q1: To what extent are sustainability competencies present in the area of Didactics of Mathematics?
- Q2: Is the presence of the identified sustainability competencies homogeneous at all levels of mastery?
- Q3: Are the competencies related to sustainability present in the different degrees taught in the area of Didactics of Mathematics in a homogeneous manner or are there differences between the degrees analyzed?
- Q4: To what extent are sustainability competencies present in each of the syllabi of the subjects of the area of Didactics of Mathematics?

2.2. Sampling Method

The chosen sampling method is purposive and reduced. It is related to the interest [27] in analysing the extent to which sustainability competencies are present in the syllabi of the subjects of the area of Didactics of Mathematics in the Faculty of Sciences of Education at the Universidad de Cádiz.

In this study, we analysed the official syllabi for the area of Didactics of Mathematics, not the teaching guides developed by the teachers as they were not available in many cases.

The nine syllabi (study programmes) belong to three different degrees:

- Degree: Degree in Early Childhood Education (DECE), Degree in Primary Education (DPE), Master's degree in Teacher Training in Compulsory Secondary and Upper Secondary School Education (MASE).
- Subject: Mathematical Knowledge in Early Childhood Education (MK), Development of Mathematical Knowledge in Early Childhood Education (DMK), Mathematical Knowledge in Primary Education 1 (MK1), Mathematical Knowledge in Primary Education 2 (MK2), Didactics of Mathematics 1 (DM1), Didactics of Mathematics 2 (DM2), Training Complements of Mathematics (TCM), Learning and Teaching Mathematics (LTM), Teaching Innovation and Initiation to Research in teaching of Science and Mathematics (IISM).

2.3. Instruments

For the data analysis, two tools from two complementary theoretical frameworks were used as instruments in this work: the Model of the Green Curriculum in Higher Education (ACES Model) and the Map of generic Sustainability Competencies for Education Degrees developed within the framework of the EDINSOST project. We briefly describe each of them below.

- Model of the Green Curriculum in Higher Education (ACES Network):

At an international level, since 2000, the ACES Network, made up of eleven universities (five European ones and six Latin American ones), constitutes one of the main references in terms of including sustainability in the curriculum, working on the design of models, criteria, and instruments for a greener higher education. Based on how this network conceptualises incorporating sustainability into the curriculum, the characterisation of a 'green' study includes the following ten characteristics [13]:

1. (C1) Integrate complexity
2. (C2) Flexibility in the disciplinary order
3. (C3) Contextualisation in space (local/global) and in time (historically/in the present/and with a view to the future)

4. (C4) Take the subject into account in the construction of knowledge
5. (C5) Consider the cognitive, affective, and action-related aspects of people
6. (C6) Consistency and interaction between theory and practice
7. (C7) Prospective orientation of alternative scenarios, encouraging critical thinking and responsible decision-making, considering possible future scenarios
8. (C8) Methodological adequacy
9. (C9) Generate spaces for reflection and democratic participation
10. (C10) Commitment for the transformation of society-nature relations.

Likewise, the ACES Network has defined a series of criteria for each of the aforementioned characteristics that allow approaching the diagnosis of greening a study. In addition, these criteria for a greener curriculum can be applied in very different scales and areas of work: curricula, study programmes, institutional regulations (strategic plans, etc.), research, and university extension [13]. For its part, the Professional Development Research Group of the Teacher-HUM462 of the Universidad de Cádiz has translated those characteristics (Figure 1, inner ring) into a language that is closer and adapted to our socio-educational reality (Figure 1, outer ring), opting for the term Educating for Sustainability [28]. The adaptation of this instrument, which is organised in a set of categories and indicators that reflect the principles of sustainability in educational terms, can be consulted in Azcárate et al. [29].

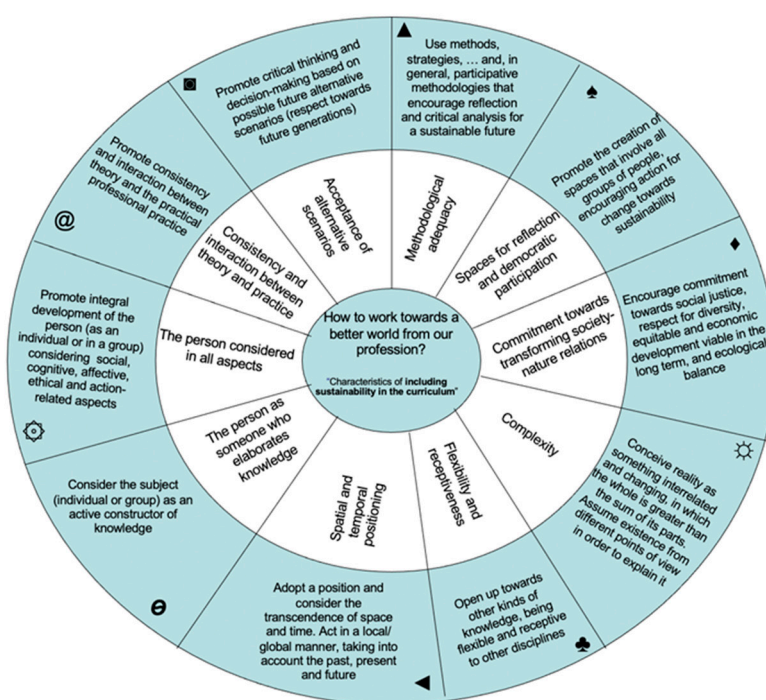


Figure 1. Educating for Sustainability (Adaptation from the ACES network proposal).

- Map of EDINSOST's generic competencies in sustainability:

The research project EDINSOST: education and social innovation for sustainability; training of professionals as agents of change in Spanish universities to face the challenges of society, is an R&D and innovation project of the state research, development, and innovation programme oriented towards the challenges of society, EDU2015-65574-R, financed by the Ministry of Economy, Industry and Competitiveness in Spain.

In Spain, the Sectoral Commission of the CRUE-Sustainability [19] has defined four sustainability competencies, described in Section 1, which are the starting point of the map of sustainability competencies in education [24], developed within the framework of the EDINSOST project.

A competency map is a double entry matrix made up of a series of learning outcomes organised from a series of competency units and a set of mastery levels for each competency unit (map cells).

The map of sustainability competencies for education degrees is configured around six competency units (SUS1.1 to SUS4.2, see Table 1). These six competency units accurately describe the four cross-curricular sustainability competencies defined by the CRUE-Sustainability [19] by means of a series of learning outcomes. Learning outcomes are classified into three levels of mastery (L1 = “know”, L2 = “understand”, and L3 = “show + do”), in accordance with an adaptation of the taxonomy proposed by Miller [30]. Table 1 shows the four sustainability competencies defined by the CRUE-Sustainability [19] and the six competency units of the map of sustainability competencies for education degrees from the EDINSOST project. A complete version of the map of sustainability competencies for education degrees (6 competency units \times 3 mastery levels = 18 cells), which includes the set of desirable learning outcomes organised into the three mastery levels described above (different levels of progression in the acquisition of each of the competencies), can be consulted in Muñoz-Rodríguez, et al. [26].

Table 1. Map of sustainability competencies in higher education [26] (simplified).

CRUE Competencies	Competency Units
SUS1. Competency in the critical contextualisation of knowledge through interrelating social, economic and environmental issues at a local and/or global level	SUS1.1. Understands the functioning of natural, social, and economic systems, as well as their interrelationships and problems, both at a local and global level
	SUS1.2. Possesses critical thinking skills and creativity, taking advantage of the different opportunities that arise (ICTs, strategic plans, regulations, etc.) in planning a sustainable future
SUS2. Competency in the sustainable use of resources and in the prevention of negative impacts on the natural and social environment	SUS2.1. Designs and develops actions, making decisions that take into account environmental, economic, social, cultural and educational impacts to improve sustainability (includes anticipatory thinking)
SUS3. Competency to participate in community processes that promote sustainability	SUS3.1. Promotes and participates in community activities that promote sustainability
SUS4. Competency to apply ethical principles related to sustainability values in personal and professional behaviour	SUS4.1. Is consistent in actions, respecting and valuing (biological, social, and cultural) diversity and committed to improving sustainability
	SUS4.2. Promotes an education in values oriented towards training responsible, active, and democratic citizens

2.4. Data Analysis

As pointed out by Azcárate, et al. [29] (p. 269), “one of the most important tasks in research is to decide what to observe and register for each element of the sample and the data it provides us with”. The sources of information in this work were the study programmes of the subjects of the area of Didactics of Mathematics in the Faculty of Education Sciences at the Universidad de Cádiz. The analysis process was performed in the syllabi of said subjects.

The map of generic sustainability competencies developed within the framework of the EDINSOST project (Table 1) can be used as an instrument to evaluate the presence of sustainability competencies of any syllabus or study programme [24]. However, in this study, the search for keywords in the study programmes of the subjects under study was not enough since, in most cases, they were not designed by teachers that are experts in sustainability and, as a result, they were not drawn up in terms of sustainability.

In this regard, Antúnez [31] makes a distinction between a direct and indirect relationship of a competency with sustainability:

- Directly means that it is literally understood that the competency is related to a certain aspect of sustainability or that it promotes its development. These are competencies in which the terms “sustainability” or “sustainable development” appear literally.
- Indirectly means that the competency, although not specifically in sustainability, is consistent with sustainability and/or helps to achieve it.

In this work, competencies and learning outcomes were identified in the different study programmes related to sustainability both directly and indirectly. The review of the syllabi of the different subjects under study was carried out by members of the EDINSOST project and the Professional Development Research Group of the Teacher-HUM462, all well acquainted with the map of sustainability competencies for education degrees. The analysis, together with the discussion, review, and debate in the data analysis itself was planned in the following phases:

- In the first phase, it was considered appropriate to use content analysis as a procedure [32]. For this purpose, full meaningful texts in which the characteristics and criteria of the ACES Network featured, were taken as a reference [29]. Those characteristics and criteria were considered in the competencies and in the learning outcomes of the study programmes of each of the subjects referred to in the sample. Competencies and learning outcomes were thus identified in the study programmes of each of the subjects that had a direct or indirect relationship with sustainability.
- The direct or indirect relationship established between the competencies and the learning outcomes of the study programmes of the subjects with the sustainability principles of the ACES Model allowed, in the second phase of the study, incorporating these competencies and learning outcomes into the map of sustainability competencies developed by the EDINSOST project for each of the subjects. Furthermore, at this point, the use made of a verb in a certain statement was what determined the level of progression of the competency (L1 = “know”, L2 = “understand”, and L3 = “show + do”).
- In the third phase of the work, because of the qualitative nature of the variables in this study, for each cell of the sustainability map (18 cells in total), the percentages of appearance of competencies and learning outcomes were calculated with respect to the total number of competencies and learning outcomes of the syllabi under analysis. The sustainability presence map for each of the subjects in the area of Didactics of Mathematics (see Table 2 in Section 3) was thus created.

An example of the coding used for the units of information is the following:

DECE_DMK_SC2_IN_C3_SUS1_SUS1.1_L1: study programme analysed (DECE); subject of the study programme analysed (DMK); code of the specific competency, object of analysis (SC2); relationship of the competency with sustainability: direct/indirect (IN); characteristic of the ACES model to which the unit of information is related (C3); competency/competency unit/level of mastery the unit of information is connected with (SUS1_SUS1.1_L1).

The coding technique exemplified is linked to the competency: “knowing strategies to develop numeric, spatial, geometric representations, and of logical development”.

In accordance with the coding established previously, the case of a specific competency is shown (SC2) of the DMK subject of the DECE study programme, indirectly (IN) related to sustainability. However, it supports and promotes the use of a variety of systems of representation for the same (spatial, temporal, logical, functional, tabular, graphical, verbal, etc.) fact or phenomenon (C3_SUS1_SUS1.1) to a mastery level (L1).

The exemplified coding technique allowed us to assign competency SC2 to one of the cells of the sustainability map, more specifically to the cell of the map whose code is SUS1.1_L1 for its subsequent calculation.

3. Results and Discussion

Table 2 shows the map of the presence of sustainability, expressed in percentages, for the emerging area of Didactics of Mathematics in accordance with the methodology

described in Section 2. Said information is organised based on the different competencies, competency units and mastery levels (rows) for each subject of each degree (columns).

Table 2. Sustainability presence map in the area of Didactics of Mathematics.

Degree		DECE		DPE				MASE		
Subject		MK	DMK	MK1	MK2	DM1	DM2	TCM	LTM	IISM
SUS1: Competency in the critical contextualization of knowledge through interrelating social, economic, and environmental issues at a local and/or global level										
SUS1.1	L1	0.38	0.21	0.31	0.29	0.54	0.40	0.63	0.25	0.46
	L2	0.15	0.07	0.00	0.00	0.08	0.10	0.25	0.05	0.15
	L3	0.08	0.14	0.00	0.00	0.15	0.10	0.00	0.05	0.08
SUS1.2	L1	0.15	0.21	0.15	0.14	0.23	0.20	0.38	0.35	0.46
	L2	0.08	0.21	0.00	0.00	0.00	0.10	0.25	0.05	0.23
	L3	0.08	0.21	0.15	0.07	0.15	0.10	0.00	0.15	0.15
SUS2: Competency in the sustainable use of resources and in the prevention of negative impacts on the natural and social environment										
SUS2.1	L1	0.00	0.00	0.00	0.00	0.08	0.10	0.00	0.20	0.15
	L2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.08
	L3	0.08	0.14	0.00	0.00	0.08	0.00	0.00	0.15	0.08
SUS3: Competency to participate in community processes that promote sustainability										
SUS3.1	L1	0.08	0.07	0.08	0.00	0.08	0.10	0.00	0.15	0.00
	L2	0.08	0.07	0.00	0.00	0.00	0.00	0.13	0.00	0.00
	L3	0.00	0.07	0.00	0.00	0.08	0.00	0.00	0.05	0.00
SUS4: Competency to apply ethical principles related to sustainability values in personal and professional behaviour										
SUS4.1	L1	0.00	0.00	0.08	0.14	0.00	0.00	0.13	0.25	0.00
	L2	0.08	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.08
	L3	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.05	0.08
SUS4.2	L1	0.00	0.00	0.00	0.00	0.08	0.10	0.00	0.00	0.08
	L2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	L3	0.08	0.14	0.00	0.00	0.08	0.00	0.00	0.05	0.00

The columns in Table 2 show the subjects analysed, organised per degree programme:

- Degree: Degree in Early Childhood Education (DECE), Degree in Primary Education (DPE), Master's degree in Teacher Training in Compulsory Secondary and Upper Secondary School Education (MASE).
- Subject: Mathematical Knowledge in Early Childhood Education (MK), Development of Mathematical Knowledge in Early Childhood Education (DMK), Mathematical Knowledge in Primary Education 1 (MK1), Mathematical Knowledge in Primary Education 2 (MK2), Didactics of Mathematics 1 (DM1), Didactics of Mathematics 2 (DM2), Training Complements of Mathematics (TCM), Learning and Teaching Mathematics (LTM), Teaching Innovation and Initiation to Research in teaching of Science and Mathematics (IISM).

The rows in Table 2 show the presence of sustainability, expressed in percentages, for each competency SUSi.j in each of the three mastery levels considered (L1, L2, L3).

In this section, to answer the four research questions, several figures are shown below representing the relative presence of sustainability competencies, expressed in percentages, defined by the CRUE-Sustainability [19] in the area of Didactics of Mathematics. The different figures represent said presence globally, per degree, and in the study programmes of each of the subjects, in terms of competencies, units of competency and mastery levels. The different figures illustrate the results synthesised in Table 2.

3.1. Presence of Sustainability Competencies in the Area of Didactics of Mathematics

Figures 2 and 3 enable answering the first research question (Q1): To what extent are sustainability competencies present in the area of Didactics of Mathematics?

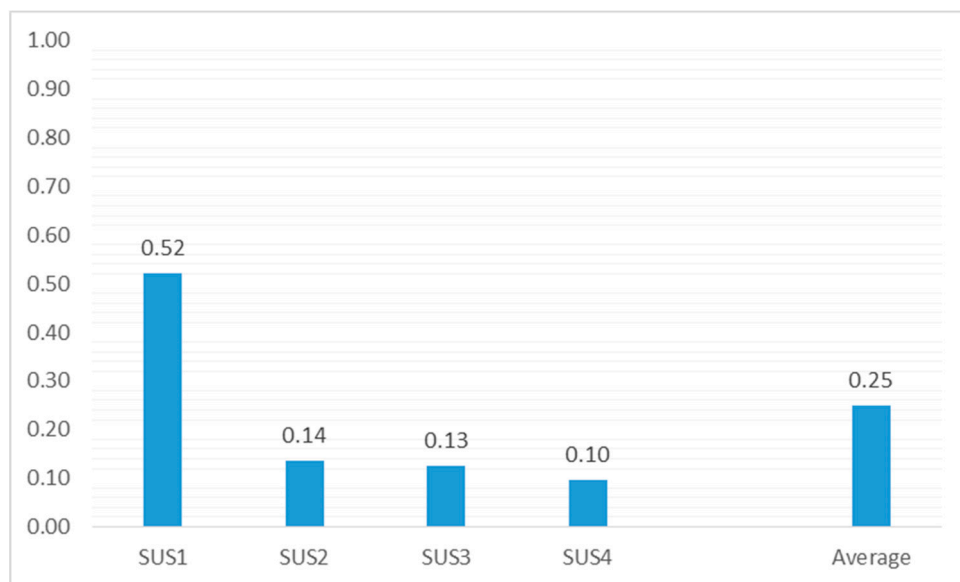


Figure 2. Average presence of sustainability competencies in the area of Didactics of Mathematics and weighted average.

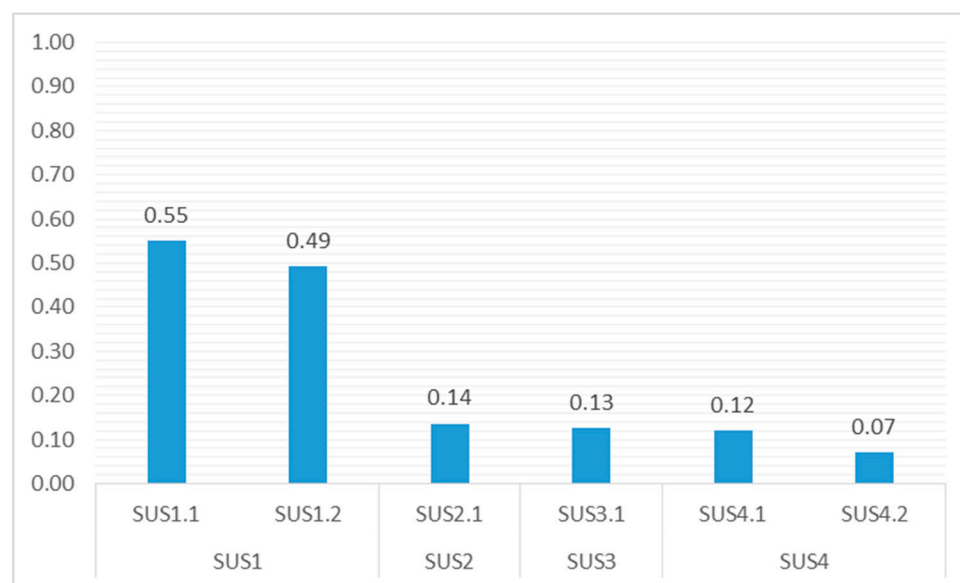


Figure 3. Average presence of sustainability competencies in the area of Didactics of Mathematics broken down by competency units.

Figure 2 shows the relative presence, expressed in percentages, of the four sustainability competencies in the area of Didactics of Mathematics and the weighted average. It is observed that the relative presence of the four competencies is different. The SUS1 competency (critical contextualisation of knowledge [. . .]) is the most present in the area of Didactics of Mathematics (52%), which is far from the relative presence shown for the rest of the competencies. On average, the relative presence of sustainability competencies in the area of Didactics of Mathematics is only 25%.

Figure 3 shows the relative presence, expressed in percentages, of the four sustainability competencies in the area of Didactics of Mathematics, broken down by competency units.

Figure 3 corroborates the behaviour observed in Figure 2 in terms of a gradually diminishing presence of sustainability competencies in the area of Didactics of Mathematics, when proceeding from the SUS1 competency (critical contextualisation of knowledge [...]), which has a presence of 55% for SUS1.1 (understands the functioning of systems, as well as their interrelationships, both locally and globally [...]) to the SUS4 competency (applying ethical principles [...]). Only 7% presence is observed for SUS4.2 (promotes an education in values oriented towards training responsible, active, and democratic citizens [...]).

In the results of this research, it is worrying to see how, having a longstanding experience in education degrees, the competency (SUS4) to apply ethical principles related to the values of sustainability in both personal and professional behaviour is the one with the least presence in the area of Didactics of Mathematics (10% on average, see Figure 2). Ethics seems to evade the focus of attention of mathematical educators, either because it is considered as secondary or because it is taken for granted [7]. However, mathematics educators must be critical and respond in a committed manner not only with regard to achieving mathematical knowledge but also democracy, social justice, ethics, and solidarity, pillars of a responsible educational intervention in our environment [33]. In today's world, mathematics education must provide essential tools to exercise critical and democratic citizenship [2]. Nonaka and Konno [34] defend establishing dialogic approaches to real-world issues. Dialogic education promotes the creation of knowledge from a critical perspective of a reality in a democratic and emancipatory manner [35]. Problem-based and project-based learning are manifestations for a critical education [2] in line with this approach. The explicit inclusion of this type of methodologies in the study programmes of the subjects is a necessary ethical choice for the training of teachers who engage in critical and reflective thinking, as it enables them to make decisions in a responsible, fair, committed, and informed manner in their daily work.

3.2. Mastery Levels in Which Each of the Sustainability Competencies Is Developed in the Area of Didactics of Mathematics

Figure 4 enables answering the second research question (Q2): Is the presence of the identified sustainability competencies homogeneous at all levels of mastery?

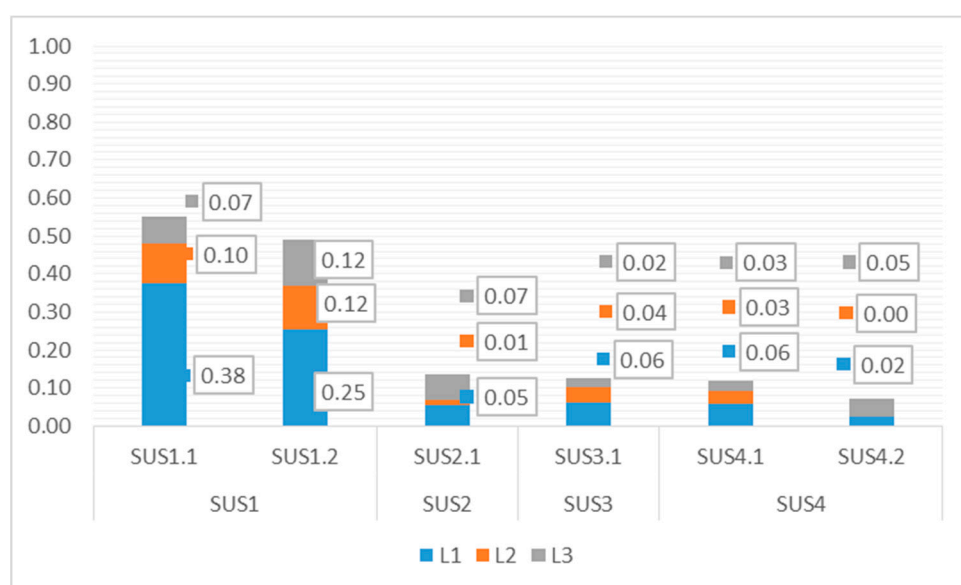


Figure 4. Average presence of sustainability competencies in the area of Didactics of Mathematics in accordance with the mastery levels in which each one is developed.

Figure 4 shows the relative presence, expressed in percentages, of the four sustainability competencies in the area of Didactics of Mathematics broken down by competency units, and according to these units, they are developed at one level of mastery or another (L1, L2, or L3).

One of the problems that competency assessment causes is that it is the result of a sequenced process [36]. Education for sustainable development proposes the training of competent citizens to identify and “know” (L1) the problems of the world in which they have lived, “understand” them (L2) holistically, and intervene and “act” (L3) for the change in favour of solving them [37].

A different, non-homogeneous presence is observed in Figure 4 in the three levels of mastery. The lowest level (L1 = “know”) is the one with the greatest presence in all the competency units except in SUS2.1 (designs and develops actions to minimise the environmental, economic, social, educational, and cultural impact to improve sustainability [. . .]) and SUS4.2 (promotes an education in values aimed at training responsible, active and democratic citizens [. . .]), in which mastery level L3 (“to show + do”) is the most present. These results are consistent with other studies that show how, in education degrees, the lowest levels (L1) are those that, in general, have a greater presence [25]. More generally, several studies and reports have identified how society perceives universities as (unidirectional) transmitting institutions of knowledge and as institutions disconnected from real problems [38].

Schools, even the university school, tend to convey solutions, not problems [39]. However, limiting training in mathematics education to reproducing knowledge of heuristics and formulas for calculus (mathematical knowing) that only model certain problems is to deny an increasingly systemic, dynamic, and complex reality. An opportunity for future teachers to acquire professional competencies for teaching mathematics to deepen their knowledge [40] is to design problems that promote student learning.

Working in mathematics education around the design of problems or realistic projects (not traditional or close-ended single-response problems) would allow the development of a level of “action” (L3) that cannot take place without an “understanding” (L2) of and prior reflection on these problems. Mathematical modelling would also enable promoting consistency and interaction between the theoretical (mathematical-neutral) discourse and professional ethical-practical action [2]. According to Korthagen [41], the ideal process for reflective learning consists precisely in an alternation between action, even if it seems innocuous, and reflection. It is a process of deconstruction and co-construction of knowledge [23] that allows creating awareness of critical structures in society. Moreover, this kind of methodology based on solving problems in direct connection with reality are considered an important approach for teaching and learning about sustainability issues, learning to think about the consequences of actions (SUS2.1), and about how societies can adapt to ensure a more sustainable future [42].

3.3. Presence of Sustainability Competencies in the Different Degrees

Figures 5 and 6 enable answering the third research question (Q3): Are the competencies related to sustainability present in the different degrees taught in the area of Didactics of Mathematics in a homogeneous manner or are there differences between the degrees analysed?

Figure 5 shows the relative presence, expressed in percentages, of the six units of sustainability competencies in the area of Didactics of Mathematics itemised by degrees: the degree in Early Childhood Education (DECE), the degree in Primary Education (DPE), and the Master’s degree in Teacher Training for Compulsory Secondary and Upper Secondary School Education (MASE). A different presence, but similar behaviour of the sustainability competencies in the three degrees analysed in the area of didactics of mathematics is observed. Figure 5 illustrates how all the competency units are present in the three degrees, and especially relevant are SUS1.1 (understands the functioning of systems, as well as their interrelations, both at a local and global level [. . .]) and SUS1.2 (possesses critical

thinking skills and creativity [...]) that correspond to the two competency units linked to the SUS1 competency (critical contextualisation of knowledge [...]) defined by the CRUE-Sustainability [19]. The reason that made this diagnosis of greater presence possible for these two units of competency has to do with the inclusion of competencies and learning outcomes in the study programmes of subjects such as: “Promoting critical awareness”, “Creative problem-solving”, or “Analysing the historical development of knowledge as a source of information in the classroom”, amongst others.

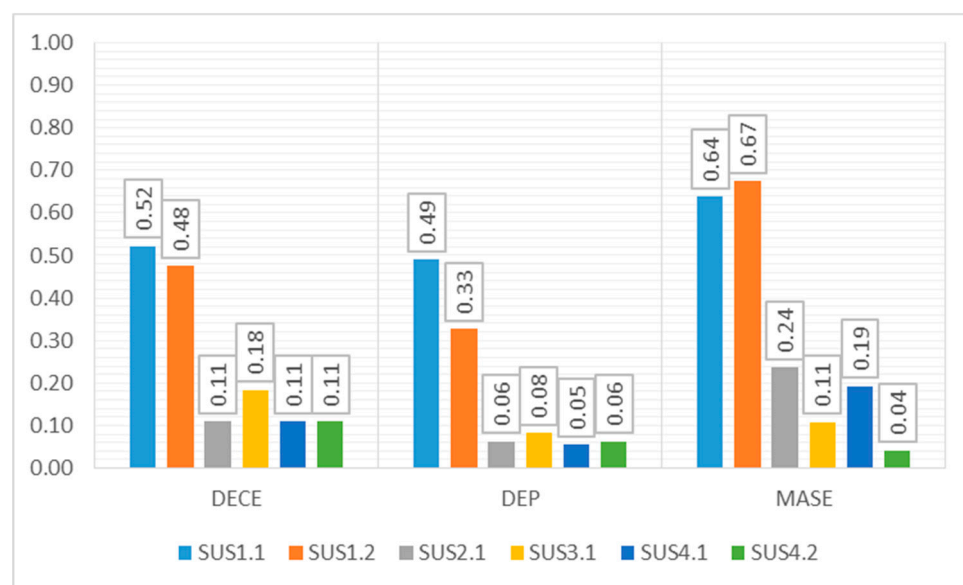


Figure 5. Average presence of sustainability competencies in the area of Didactics of Mathematics broken down by degree programmes.

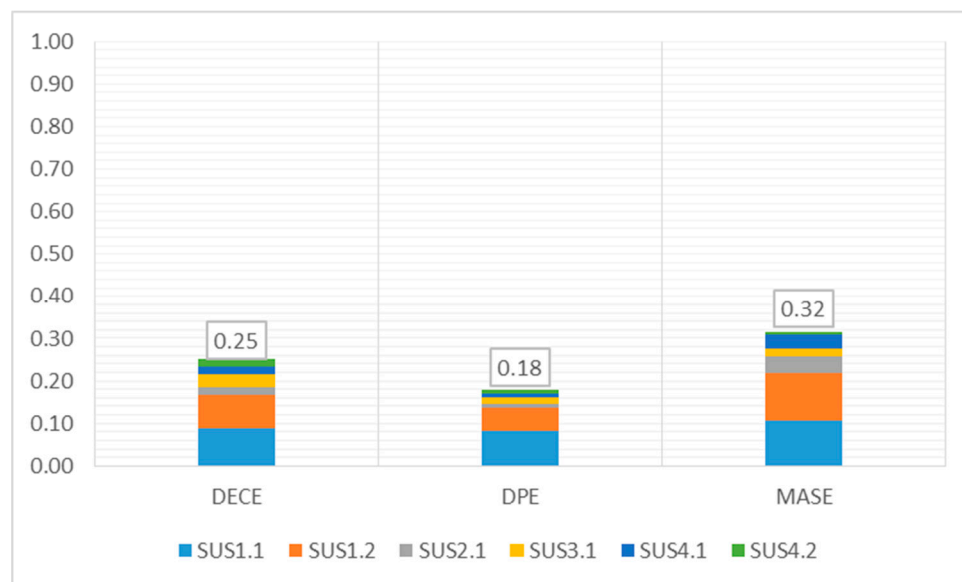


Figure 6. Contribution to the development of the sustainability competency in the area of Didactics of Mathematics in each degree.

However, there are a small number of explicit and direct references to the training of a teacher profile in mathematics connected to the environment, that is, qualified to understand the interwoven relationships that take place between natural, social, economic, and cultural environments [23]. However, understanding these types of interrelationships

is essential in order to identify the causes of real problems, since most of these problems are not well defined and are often open problems [43].

Figure 6 contains the same information as Figure 5, but in a stacked and standardised manner. Figure 6 shows the relative presence, expressed in percentages, of the six units of sustainability competencies for each degree in the area of Didactics of Mathematics in a single bar (stack). The purpose of Figure 6 is to complement the information shown in Figure 5, indicating the degree of global contribution to the sustainability competency in each degree analysed. To do so, the methodology assumes that each of the six sustainability competency units contributes 16.6% (1/6) to the global sustainability competency.

As can be seen in Figure 6, MASE is the degree that most contributes to the global development of the sustainability competency in the area of Didactics of Mathematics (32%), followed by the DECE (25%) and the DPE (18%). These results represent, on average, a global contribution to the development of the sustainability competency in the area of Didactics of Mathematics of 25%, consistent with the results shown in Figure 2.

3.4. Presence of Sustainability Competencies in the Study Programmes of the Subjects

Figures 7–9 enable us to answer the fourth research question (Q4): To what extent are sustainability competencies present in each of the syllabi of the subjects of the area of Didactics of Mathematics?

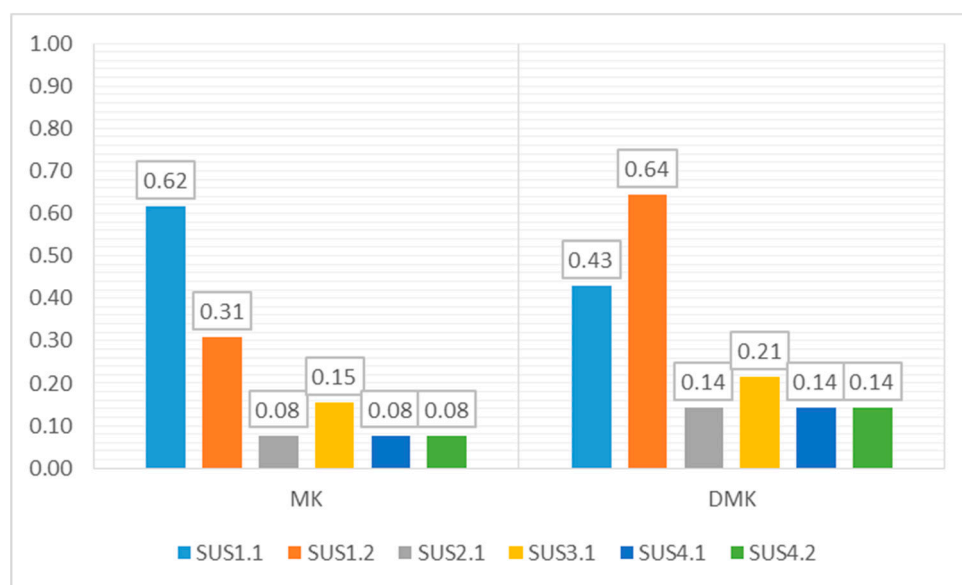


Figure 7. Presence of sustainability competencies in the degree in Early Childhood Education broken down by subjects.

3.4.1. Presence of Sustainability Competencies in the Degree in Early Childhood Education

Figure 7 illustrates the relative presence, expressed in percentages, of the six units of sustainability competencies in the subjects of MK (Mathematical Knowledge in Early Childhood Education), and DMK (Development of Mathematical Knowledge in Early Childhood Education), which are taught in the degree in Early Childhood Education (DECE) in the area of Didactics of Mathematics.

Figure 7 shows a different presence, but similar behaviour of the sustainability competencies in the two subjects analysed in the degree in Early Childhood Education. The most notable percentage difference is found in the presence of the SUS1.2 competency in these two subjects (31% presence for MK versus 64% for DMK) and, in general, there is a greater presence of all the competencies in sustainability in DMK than in MK (with the exception of SUS1.1).

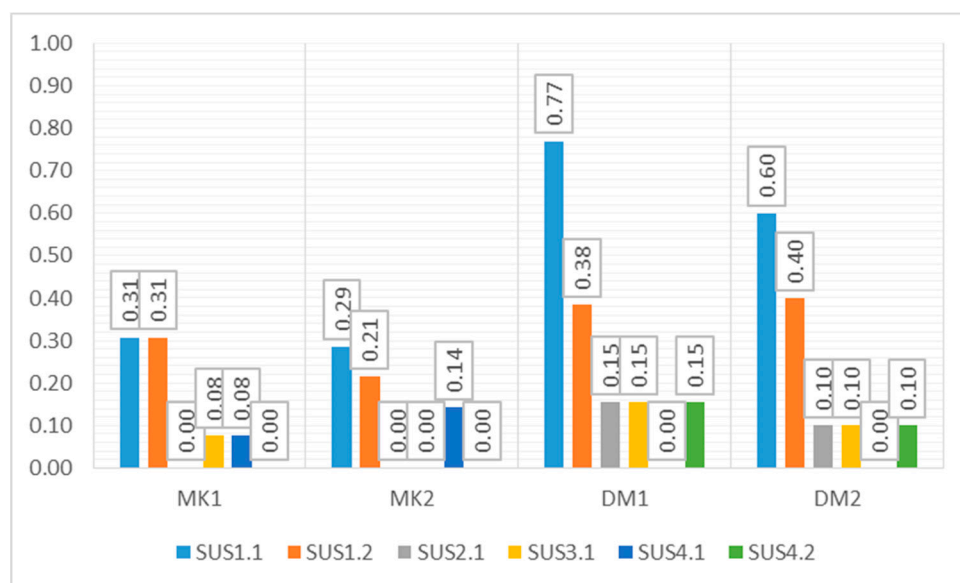


Figure 8. Presence of sustainability competencies in the degree in Primary Education broken down by subjects.

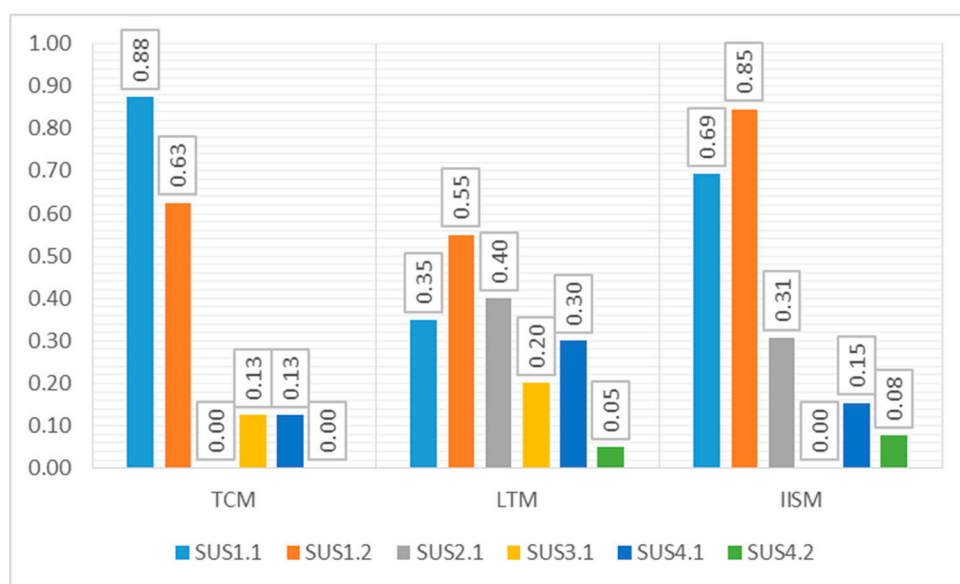


Figure 9. Presence of sustainability competencies in the Master's degree in Teacher Training in Compulsory Secondary and Upper Secondary School Education (MASE) broken down by subjects.

These results can be explained by the very nature of these two subjects. Thus, although both subjects are aimed at future teachers responsible for the mathematical training of Early Childhood Education students, and their contents seek to offer training of an integrative nature, MK places the focus on the different kinds of mathematical knowledge characteristic of this school stage (its analysis, how it is structured, how it is built, etc.). Yet, DMK focuses its attention more on aspects related to the teaching and learning processes of school mathematics in Early Childhood Education (including everything it implies: a great variability of elements and interactions the teacher uses to conceptualise the situations of teaching, learning and evaluation). Training future teachers in the development of critical, creative, and innovative thinking (SUS1.2) is especially important in this case. Furthermore, explicitly stating the competencies directly related to sustainability, such as “Elaborating didactic proposals related to the interaction of science, technique, society and sustainable

development” in the study programme of DMK also explains how this subject attains a larger presence in the sustainability competencies.

3.4.2. Presence of Sustainability Competencies in the Degree in Primary Education

Figure 8 shows the relative presence, expressed in percentages, of the six units of sustainability competencies in the subjects MK1 (Mathematical Knowledge in Primary Education 1), MK2 (Mathematical Knowledge in Primary Education 2), DM1 (Didactics of Mathematics 1), and DM2 (Didactics of Mathematics 2), taught in the degree in Primary Education (DPE) in the area of Didactics of Mathematics.

Figure 8 illustrates that in the degree in Primary Education, there is a different presence, but similar behaviour of the sustainability competencies in the four subjects analysed. However, the percentage differences are more pronounced when comparing the subjects of MK1 and MK2: “Basic Principles of the Mathematics Curriculum in School Education” with the subjects of DM1 and DM2: “Teaching and Learning of Mathematics”. The four subjects make up the module “Teaching and Learning Mathematics” in this degree (DPE).

In the study programmes of the subjects, competencies such as “promoting the development of basic skills for the teaching profession: analysis, communication, reflection, and creativity”, or “understanding elements of the history of mathematics as a science to modify the vision of its nature for teaching” are normally specified. They promote the presence of the two competency units linked to the SUS1 competency, especially in DM1 and DM2.

For their part, MK1 and MK2 are subjects that are more focused on the acquisition of basic mathematical skills (numerical, calculus, geometric, spatial representations, estimating and measuring, and data organisation and interpretation). A very low level of presence (or even zero) of sustainability competencies related to anticipatory, ethical, or participatory thinking (SUS2, SUS3 and SUS4) is observed. Exceptionally, in MK1, “appreciate the ability to work in a team” is specified, which shows a certain presence (8%) of the SUS3.1 competency unit in this subject (Figure 8).

However, training in mathematics education in connection with the principles of sustainability should go beyond simple teamwork. Training future professionals in participatory practice means laying firm foundations to build fairer, more committed, and more sustainable societies [44]. In mathematics education, favouring deconstruction processes over real problems would generate possible contradictions, ethical considerations, ambiguities and/or a certain hermeticism that, in a process of intellectual co-learning, should be endowed with meaning from otherness [7].

The better results of DM1 and DM2 with regard to presence are because they focus their attention not on the acquisition of basic mathematical competencies, but on aspects related to the teaching and learning processes of school mathematics in Primary Education. Furthermore, their study programmes include a specific competency of the practicum subject (curriculum-related practices), namely: “to know and apply the interaction and communication processes in the classroom and to master the social skills and abilities necessary to foster a classroom environment that facilitates learning and co-existence”. The practicum subject is part of the curriculum of the degree in Primary Education. Although it is not linked to the area of Didactics of Mathematics, it does contain a specific mathematics seminar in which discussions and debates take place, and guidance is provided on the consistency and interaction between theory and practice [41]. Adopting a teacher–researcher attitude that questions educational processes from the contributions of educational research and formalised academic knowledge is encouraged in this subject.

3.4.3. Presence of Sustainability Competencies in the Master’s Degree in Teacher Training in Compulsory Secondary and Upper Secondary School Education (Specialisation in Mathematics)

Figure 9 shows the relative presence, expressed in percentages, of the six units of sustainability competencies in the subjects of TCM (Training Complements in Mathematics), LTM (Learning and Teaching of Mathematics), and IISM (Teaching Innovation and Initiation

to Research in the teaching of Science and Mathematics) taught in the Master's Degree in Teacher Training in Compulsory Secondary and Upper Secondary School Education (MASE) in the specialisation in Mathematics in the area of Didactics of Mathematics.

Figure 9 shows, once again, a different presence, but similar behaviour of the sustainability competencies in the three subjects analysed of the Master's degree in Teacher Training in Compulsory Secondary and Upper Secondary School Education in the specialisation of mathematics.

Training Complements of Mathematics (TCM) and Teaching Innovation and Initiation to Research in the teaching of Science and Mathematics (IISM) are the subjects with the lowest presence of sustainability competencies in general, except for the two competency units linked to the SUS1 competency.

In particular, in TCM, the high presence for the SUS1.1 competency (88%) is because it is a subject that promotes, amongst others, "having a vision of the nature of mathematics, which integrates epistemological, sociological, and axiological aspects", adopting a historical and current perspective, and that considers mathematics as a product of human activity. The object of this subject is the study of different perspectives and currents on the nature of mathematical knowledge: logicism, formalism, and intuitionism, and it even considers the critical view of the philosophy of mathematics education. In contrast, in IISM, the high presence for the SUS1.2 competency (85%) is justified because it is a subject whose object of study is focused on knowing innovative researched approaches for teaching in the fields of science and mathematics, promoting the development of a critical and creative thinking competency in teacher training.

For its part, Learning and Teaching Mathematics (LTM), whose object of study is the analysis of all those aspects related to the teaching and learning processes of mathematics in Compulsory Secondary and Upper Secondary School Education, shows, in general, a higher presence in the development of sustainability competencies. In some competencies, it is even higher than in the case of the subjects of the DECE (Figure 7) or the DPE (Figure 8). MASE is a degree of a more professional nature in the sense that it enables the practice of the regulated teaching profession in Compulsory Secondary and Upper Secondary School Education for students who already have a university degree. MASE also enables the subsequent development of a doctoral degree.

3.5. Limitations of the Study

The following limitations were encountered in this research study:

- The distinction of the four sustainability competencies defined by the Sectoral Commission of the CRUE-Sustainability [19] is more analytical than real in the sense that, as an example, proper development of the SUS3 competency ("participation in community processes that promote sustainability [. . .]") can have an influence –in practice– on optimal development of the SUS4 competency (applying ethical principles [. . .]). It is not without reason that strengthening global perception leads to the strengthening of ethical values such as solidarity or responsibility [45]. From a holistic perspective, the four sustainability competencies are interrelated and cannot be considered as watertight compartments. This study is therefore understood as part of the diagnosis of the presence of sustainability competencies in the area of Didactics of Mathematics (based on the documentary and curricular analysis of the study programmes of the different subjects that constitute this area of knowledge). The authors are currently working on the analysis of the perception students have with regard to the acquisition of said sustainability competencies, as a result of the implementation of the syllabi that were the object of study in this research.
- In a line of argument similar to what has been said before, we should also be aware that, due to the great variability of elements and interactions teachers can use to conceptualise teaching-learning situations, they may make a subjective interpretation of the study programme for which they are responsible. Part of the future work to be carried out by the authors consists of accurately analysing the perceptions teachers

in the area of mathematics have regarding their training in competencies related to sustainability through interviews.

- Moreover, according to Biggs [46], the different levels of understanding, from a superficial level of thinking to a deeper one, are reflected in the use of verbs. An appropriate use of verbs helps formulating competencies better and reduces the ambiguity of the terms used [47]. In the analysis performed, competencies were encountered that, although they may seem clear, it would be desirable to reformulate them in order to better define the level of mastery or progression required to achieve them.
- Finally, it should be noted that since it is a qualitative study, we are not concerned with the generalisation of the results, although the findings could be transferred to similar contexts or settings [48]. The aim of this research was to know and understand the phenomenon under study in order to be able to characterise it and evaluate the problem.

4. Conclusions

Target 4.7 of SDG 4, quality education, for the sustainable development of the 2030 Agenda considers education as a basic instrument to promote education for sustainable development from the different areas of knowledge.

Mathematics has the power to shape society, however, it is not clear that the simple accumulation of mathematical knowledge produces any ethical competency [2]. Making mathematics education more sustainable would encourage the development of reflective knowledge as an inherent part of mathematical literacy within the framework of critical mathematics education, which seeks to train citizens who engage in critical and reflective thinking and are able to make decisions in a justified and informed way that allows their empowerment.

The presence of the CRUE-Sustainability [19] competencies in the study programmes of the subjects in the area of Didactics of Mathematics of the Faculty of Education Sciences at the Universidad de Cádiz was analysed in this paper.

Considered at a global level, the relative presence of sustainability competencies in the area of Didactics of Mathematics is barely 25% on average. The competency related to ethical aspects (SUS4) has the lowest relative presence: 10%. In contrast, promoting a critical contextualisation of knowledge together with encouraging the development of critical and creative thinking in students (SUS1) shows a relative presence of 52%. In general, the achievement of competencies related to sustainability in the study programmes of the subjects is for the most part established at the lowest level of mastery (L1 = 'know').

In the three degrees analysed, the relative presence of sustainability competencies is different, although similar behaviour is observed in the global results. The Master's degree in Teacher Training in Compulsory Secondary and Upper Secondary School Education (specialisation in mathematics) is the degree that, thanks to its professional nature, contributes the most to the development of the sustainability competency (32%), followed by the degree in Early Childhood Education (25%), and the Degree in Primary Education (18%).

These results are only the diagnosis resulting from the documentary and curriculum analysis addressed in this research. Parallel to this study, others are being carried out that focus on the perception of learning students have and on the training of teachers in the area of Didactics of Mathematics regarding sustainability competencies in order to integrate sustainability into the curriculum of the subjects.

Making mathematics education more sustainable in higher education requires an in-depth study that ensures explaining the principles that guide educational practice in the training of mathematics teachers in accordance with the critical view of the philosophy of mathematics education. The educational concern, also in the area of mathematics, for the development of critical citizenship, makes it necessary to make mathematics education more sustainable in order to encourage critical thinking in crisis scenarios.

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